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Genetic analysis of agronomic and biochemical variables among different tomato (*Solanum lycopersicum* L.) accessions

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Abstract: In the present study, thirty accessions of tomato were evaluated for estimation of correlation and path analysis among various quantitative and qualitative characters related to fruit yield. There were highly significant differences among the accessions for all the characters studied as per the analysis of variance. Genotypic correlation coefficients were generally similar in nature and higher in magnitude than the corresponding phenotypic correlation coefficients. The results revealed that the fruit yield plant^{-1} was significantly and positively correlated with number of fruits plant^{-1} (0.3119 and 0.3184) followed by fruit set percentage (0.2434 and 0.2499), fruit weight (0.6766 and 0.6731), polar diameter of fruit (0.4687 and 0.4635) at genotypic and phenotypic level, respectively, indicating that effective improvement in fruit yield plant^{-1} through these characters could be achieved. Fruit weight showed positive and significant genotypic and phenotypic correlation with fruit yield plant^{-1} by having greatest positive direct effect (1.1298 and 1.1116) on fruit yield plant^{-1} at both levels, indicating the true relationship between them and the feasibility to exploit the potentiality of this trait for effective direct selection to improve fruit yield plant^{-1}.

Keywords: Agronomical, Biochemical variables, Genetic association, Path analysis, *Solanum lycopersicum*

INTRODUCTION

Tomato (*Solanum lycopersicum* L.), a member of the Solanaceae family, is a significant vegetable crop of special economic importance in the horticultural industry worldwide (He *et al*., 2003; Wang *et al.*, 2005; Liu *et al*., 2007). It has a chromosome number of 2n=24 (Rick, 1969). Tomato is native of West Coast of South America (Mexico and Peru) and was cultivated by Indians about 500 B.C. long before arrival of Spaniards (Rehman *et al*., 2000; Tasisa *et al*., 2012; Meena and Bahadur, 2015a). In India, tomato occupies an area of 0.87 million hectares with a production of 17.50 million tonnes and productivity of 20.11 tonnes per hectare (FAO, 2012). Tomato has been identified as a functional and ''nutraceutical'' food (Canene-Adams *et al*., 2005; Adalid *et al*., 2010). A nutraceutical is any substance considered a food, or part of a food, that provides medical or health benefits, including disease prevention and treatment (Jack, 1995). Tomatoes are a rich source of fibre, vitamins A, C, and lycopene and epidemiological studies indicate that increased consumption of tomato lycopenes is co-incident with a lower occurrence of cardiovascular disease (Arab and Steck, 2000; Sesso *et al*., 2003) and certain types of cancers (Giovannucci, 2002a,b; Giovannucci *et al*., 2002). Recently, the validity of these types of association studies for lowering cancer risks has been questioned (Boffetta *et al*., 2010), but the evidence supporting the health benefits of tomato consumption remains strong (Willett, 2010). Tomatoes are consumed in many ways, the fresh fruits are eaten in salads, sandwiches and as salsa and the processed varieties are consumed dried or as pastes, preserves, sauces, soups and juices (Chatterjee, 2013). Dishes featuring tomatoes are both traditional and interwoven into the culture of many countries and there are many types of tomatoes with diverse uses which explain its global appeal (Beckles, 2012).

Efforts are being made to increase its productivity by developing superior varieties. However, yield is a complex character, the result of the expression and association of different character, which are highly in-fluenced by the environment (Amorim *et al*., 2008; Santos *et al*., 2014a) and its direct improvement is difficult. Knowledge in respect of the nature and magnitude of associations of yield with various component characters is a pre requisite to bring improvement in the desired direction. A crop breeding programme, aimed at increasing the plant productivity requires consideration not only of yield but also of its

components that have a direct or indirect bearing on yield (Tiwari and Upadhyay, 2011). The development of an effective improvement programme depends upon the existence of genetic variability (Meena and Bahadur, 2013) and knowledge of genotypic and phenotypic correlation of yield components. High genetic variability will increase the chances of establishing superior accessions/genotypes successfully in subsequent generations of selection (Hallauer and Miranda Filho, 1988; Grigolli *et al*., 2011). Correlation study measures the natural relationship between various traits and helps in determining the component traits on which selection can be based for yield improvement (Cruz and Regazzi, 2006; Grigolli *et al*., 2011; Izge *et al*., 2012). In spite of being an easily obtained statistical parameter, care must be taken in interpreting the magnitude of a correla-tion since it is hampered by the direction, by the difference in importance of the character, by the effect of two or more character, and by the effect of environment on expression of the character. In addition, correlation does not allow inferences regarding cause and effect, and so knowledge of the type of association that governs the pair of character is not possible (Furtado *et al*., 2002). This information, which is indispensable for breeding, can be obtained by means of path analysis. The technique of path coefficient analysis was developed by Wright (1921) and demonstrated by Dewey and Lu (1959) as a means of separating direct and indirect contribution of various traits. It is a standardized partial regression coefficient analysis. It measures the direct influence of one variable upon another and permits the separation of correlation coefficient into components of direct and indirect effects (Hartwig *et al*., 2007). The use of this technique has been reported to require cause and effect situation among the variables according to Singh and Chaudhary (1977); Silva *et al*. (2005). Path coefficient analysis is also very useful in formulating breeding strategy to develop elite accessions/genotypes through selection in advanced generations. Thus, the nature and magnitude of variability present in the gene pool for different characters and relationship with each other determine the success of genetic improvement of a character. Since the pattern of inheritance of quantitative characters is highly complex, therefore the present investigation was undertaken to estimate character associations and their direct and indirect effects on yield to facilitate the selection of suitable superior accessions for development of new varieties/ hybrids using standard breeding programme.

MATERIALS AND METHODS

Experimental site: A field study was carried out during the season 2012-13 at Vegetable Research Farm, Department of Horticulture, Sam Higginbottom Institute of Agriculture, Technology and Sciences, Allahabad, India. The city is situated in south-eastern part of the state Uttar Pradesh, India (25° 28' N latitude and 81° 54' E longitude) and at a mean altitude of 98 m above sea level. Geologically, the area forms a part of the Indo-Gangetic alluvial plains.

Climate and soil characteristics: The climate of Allahabad is characterized as humid sub-tropical with an average annual rainfall of 1027 mm (40.4 inches). The rainfall is monsoonal in nature with around 75% received during July-September. The soil of the experimental field was loamy sand in texture, low in available nitrogen and organic matter, comparatively rich in available phosphorus and medium in available potassium with slightly alkaline reaction. The mean weekly agro-meteorological observations were recorded during the crop season (Fig. 1).

Plant materials: The plant materials comprised of thirty indigenous accessions of determinate tomato collected from Indian Institute of Vegetable Research (IIVR), Varanasi and Vegetable Research Station (VRS), Junagadh Agricultural University, Junagadh, India (Table 1).

Seed sowing, transplanting and cultivation: For raising good and healthy seedlings, the seeds were treated with carbendazim using 2.0 g per kg of seed. After that the seeds of thirty accessions of tomato were sown in the nursery bed on 30 September, 2012 and their seedlings were transplanted on 1th November, 2012 in small plots (2.0 m × 2.40 m) where row-to-row and plant-to-plant spacing was 60 cm x 50 cm that contained 16 plants. The experiment was laid out in a randomized complete block design (RCBD) with three replications.

Fertilizer application and intercultural operation: All the recommended agronomic package of practices were followed (such as earthing up, irrigation, weeding, fertilization and other cultural practices), as recommended for commercial tomato production. Irrigation water was applied into the plots at 6 to 10 days intervals as required from transplanting to final harvest. Farmyard manure, NPK (given through urea, DAP and muriate of potash, respectively) fertilizer at the rate of 20 tons, 100, 70, 60 kg/ha, respectively was applied into the field. One third of N and the entire dose of farmyard manure, P and K was applied at the time of final land preparation while remaining N was applied at two equal installments, 30 and 50 days after transplanting. Weeding was done as at when required.

Experimental data: The observation were recorded on five randomly selected plants per replication for each accession on fifteen quantitative characters *i.e*.,

Plant height (cm): The plant height was recorded by measuring the height of randomly selected plants in each plot from the ground level to the main apex; mean values were expressed in cm. The measurement was done at the time of maturity.

Number of branches plant^{-1}: Number of branches plant^{-1} were counted at the maturity stage and means were computed.

Number of leaves plant^{-1}: Counting the number of

Table 1. Collection of different accessions.

S.N.	Name of Accession	Source	S. N.	Name of Accession	Source
1.	2011/TODVAR-01	IIVR, Varanasi	16.	EC 620533	IIVR, Varanasi
2.	2011/TODVAR-03	IIVR, Varanasi	17.	EC 620545	IIVR, Varanasi
3.	2011/TODVAR-05	IIVR, Varanasi	18.	EC 620598	IIVR, Varanasi
4.	2011/TODVAR-06	IIVR, Varanasi	19.	F 3-1	IIVR, Varanasi
5.	2012/TODVAR-01	IIVR, Varanasi	20.	2012/JTL-08-06	VRS, JAU, Junagadh
6.	2012/TODVAR-02	IIVR, Varanasi	21.	2012/JTL-08-07	VRS, JAU, Junagadh
7.	2012/TODVAR-03	IIVR, Varanasi	22.	2012/JTL-08-14	VRS, JAU, Junagadh
8.	2012/TODVAR-04	IIVR, Varanasi	23.	2012/JTL-08-35	VRS, JAU, Junagadh
9.	2012/TODVAR-5	IIVR, Varanasi	24.	2012/ATL-01-19	VRS, JAU, Junagadh
10.	2012/TODVAR-6	IIVR, Varanasi	25.	2012/ATL-08-21	VRS, JAU, Junagadh
11.	2012/TODVAR-7	IIVR, Varanasi	26.	2012/ATL-08-81	VRS, JAU, Junagadh
12.	2012/TODVAR-8	IIVR, Varanasi	27.	2012/JT-03	VRS, JAU, Junagadh
13.	EC 620438	IIVR, Varanasi	28.	2012/AT-03	VRS, JAU, Junagadh
14.	EC 620452	IIVR, Varanasi	29.	Arka Alok	IIVR, Varanasi
15.	EC 620514	IIVR, Varanasi	30.	H-86	IIVR, Varanasi

Table 2. Analysis of variance for fifteen characters of tomato accessions.

S. N.	Source of Variance/ Characters	Mean Sum of Squares		
		Replication (d.f.=2)	Treatment (d.f.=29)	Error (d.f.=58)
1.	Plant Height (cm)	0.718	1666.732**	0.559
2.	Number of branches plant^{-1}	0.120	12.473**	0.166
3.	Number of leaves plant^{-1}	0.100	953.973**	0.217
4.	Days to flowering	0.165	201.589**	0.202
5.	Number of flower clusters plant^{-1}	0.396	11.558**	0.316
6.	Number of flowers plant^{-1}	0.136	270.400**	0.343
7.	Number of fruits plant^{-1}	0.004	92.438**	0.447
8.	Fruit set percentage	0.144	184.286**	0.836
9.	Fruit weight (g)	0.720	255.731**	0.308
10.	Radial diameter of fruit (mm)	0.205	73.411**	0.259
11.	Polar diameter of fruit (mm)	0.392	122.788**	0.282
12.	Fruit yield Plant^{-1} (g)	1288.108	292275.128**	1088.491
13.	Leaf curl incidence percentage	0.075	459.558**	0.083
14.	TSS °Brix	0.014	3.371**	0.017
15.	Ascorbic acid (mg/100 g)	0.112	174.688**	0.131

** Significant at 0.1%

leaves of selected sample plants and the average was recorded.

Days to flowering: To determine days to flowering, the number of days taken from date of transplanting to date of first flower opening were counted on five randomly selected plants and average worked out.

Number of flower clusters plant^{-1}: The numbers of flower clusters were counted from randomly selected plants in each plot and mean was computed.

Number of flowers plant^{-1}: The numbers of flowers were counted from lower, middle and upper clusters of selected plant; average were computed and multiplied with mean of flower clusters plant^{-1}.

Number of fruits plant^{-1}: The number of red ripe fruits from each picking were counted, added and divided by five (number of randomly selected plants from which picking was done) to get the average number of fruits plant^{-1}.

Fruit set percentage: Data on fruit set percentage was observed by dividing the number of fruits by the number of flowers cluster^{-1} and mean from lower, middle and upper part were calculated.

Fruit weight (g): The weight of 10 randomly taken fruits was measured on the electronic balance and average fruit weight was worked out.

Polar diameter of fruit (mm): Randomly picked sample fruits were used to determine the polar (stem to blossom end) diameter of the fruits with the help of a 'Vernier caliper', values were expressed in mm.

Radial diameter of fruit (mm): The radial diameter of fruits was recorded at the middle portion of the fruit with the help of a 'Vernier caliper' on the same fruit which was used for polar diameter; values were expressed in mm.

Fruit yield plant^{-1} (g): It was calculated by adding the weight of fresh red ripe fruits from each picking and dividing by five (number of randomly selected plants from which picking was done).

Table 3. Estimates of genotypic and phenotypic correlation among different traits in tomato accessions.

Characters		Plant height (cm)	No. of branches plant^{-1}	No. of leaves/ plant	Days to flower-ing	No. of flower clusters plant^{-1}	No. of flowers plant^{-1}	No. of fruits Plant^{-1}	Fruit set (%)	Fruit weight (g)	Radial diameter (mm)	Polar diameter (mm)	Leaf curl incidence (%)	TSS° Brix	Ascorbic acid (mg/100g)	Fruit yield plant^{-1} (g)
Plant height (cm)	G	**1.0000**	0.7908**	0.8001**	-0.1138	-0.2637*	-0.2249*	-0.1668	0.0122	-0.1120	-0.0312	-0.1832	0.4017**	0.0708	0.1856	-0.2309*
	P	**1.0000**	0.7761**	0.7996**	-0.1140	-0.2517*	-0.2242*	-0.1659	0.0117	-0.1117	-0.0306	-0.1827	0.4015**	0.0703	0.1849	-0.2299*
No. of branches plant^{-1}	G		**1.0000**	0.6800**	0.0165	-0.0722	-0.2632*	-0.1752	0.0384	-0.1138	0.0672	-0.1895	0.5232**	0.0017	0.1808	-0.2312*
	P		**1.0000**	0.6666**	0.0145	-0.0566	-0.2555*	-0.1755	0.0318	-0.1081	0.0637	-0.1845	0.5134**	0.0056	0.1747	-0.2272*
No. of leaves plant^{-1}	G			**1.0000**	0.0262	-0.1780	-0.1332	-0.0086	0.0810	-0.2182*	-0.2504*	-0.1652	0.2346*	-0.0039	0.0871	-0.2091*
	P			**1.0000**	0.0264	-0.1688	-0.1332	-0.0082	0.0809	-0.2174*	-0.2494*	-0.1649	0.2343*	-0.0040	0.0869	-0.2073*
Days to flower-ing	G				**1.0000**	0.0175	-0.0779	0.2519*	0.2749**	-0.0231	-0.1803	-0.2299*	-0.1495	0.0316	-0.0424	0.1965
	P				**1.0000**	0.0144	-0.0769	0.2501*	0.2724**	-0.0232	-0.1783	-0.2285*	-0.1494	0.0296	-0.0419	0.1951
No. of flower clusters plant^{-1}	G					**1.0000**	0.5393**	0.0084	-0.3065**	-0.0960	0.3147**	0.1507	-0.1417	-0.1725	-0.0653	-0.1505
	P					**1.0000**	0.5148**	0.0094	-0.2894**	-0.0914	0.2986**	0.1408	-0.1374	-0.1578	-0.0623	-0.1413
No. of flowers plant^{-1}	G						**1.0000**	-0.0350	-0.6176**	0.1508	0.3247**	0.0137	-0.1052	-0.1105	-0.2190*	-0.0102
	P						**1.0000**	-0.0346	-0.6149**	0.1503	0.3227**	0.0137	-0.1048	-0.1100	-0.2188*	-0.0104
No. of fruits plant^{-1}	G							**1.0000**	0.7967**	-0.4675**	-0.4103**	-0.1224	-0.2247*	0.1608	0.2397*	0.3119**
	P							**1.0000**	0.7985**	-0.4655**	-0.4058**	-0.1223	-0.2232*	0.1556	0.2367*	0.3184**
Fruit set per-centage	G								**1.0000**	-0.4623**	-0.5009**	-0.1130	-0.1282	0.2087*	0.3199**	0.2434*
	P								**1.0000**	-0.4604**	-0.4958**	-0.1127	-0.1276	0.2034	0.3169**	0.2499*
Fruit weight (g)	G									**1.0000**	0.5073**	0.5160**	-0.2732**	-0.1860	-0.3024**	0.6766**
	P									**1.0000**	0.5030**	0.5134**	-0.2725**	-0.1837	-0.3016**	0.6731**
Radial diame-ter (mm)	G										**1.0000**	0.1154	0.1133	-0.1205	-0.0572	0.1532
	P										**1.0000**	0.1127	0.1126	-0.1207	-0.0565	0.1503
Polar diameter (mm)	G											**1.0000**	-0.4245**	-0.2360*	-0.3016**	0.4687**
	P											**1.0000**	-0.4230**	-0.2341*	-0.3007**	0.4635**
Leaf curl inci-dence percent-age	G												**1.0000**	-0.0111	0.0114	-0.5037**
	P												**1.0000**	-0.0115	0.0115	-0.5009**
TSS°Brix	G													**1.0000**	0.8738**	-0.0521
	P													**1.0000**	0.8662**	-0.0531
Ascorbic acid (mg/100g)	G														**1.0000**	-0.0946
	P														**1.0000**	-0.0949

* and ** significant at 5% and 1% level of significance, respectively.

Table 4. Direct (diagonal) and indirect effects of component characters contributing to yield in tomato at genotypic and phenotypic level.

Characters		Plant height (cm)	No. of branches plant^{-1}	No. of leaves Plant^{-1}	Days to flower-ing	No. of flower clusters plant^{-1}	No. of flowers plant^{-1}	No. of fruits plant^{-1}	Fruit set (%)	Fruit weight (g)	Radial diame-ter (mm)	Polar diame-ter (mm)	Leaf curl incidence (%)	TSS° Brix	Ascorbic acid (mg/100g)	Fruit yield plant^{-1} (g)
Plant Height (cm)	G	**-0.0294**	-0.0232	-0.0235	0.0033	0.0077	0.0066	0.0049	-0.0004	0.0033	0.0009	0.0054	-0.0118	-0.0021	-0.0054	0.0068
	P	**-0.0320**	-0.0248	-0.0256	0.0036	0.0081	0.0072	0.0053	-0.0004	0.0036	0.0010	0.0058	-0.0129	-0.0022	-0.0059	0.0074
No. of branches plant $^{-1}$	G	-0.0279	**-0.0352**	-0.0240	-0.0006	0.0025	0.0093	0.0062	-0.0014	0.0040	-0.0024	0.0067	-0.0184	-0.0001	-0.0064	0.0081
	P	-0.0201	**-0.0259**	-0.0173	-0.0004	0.0015	0.0066	0.0045	-0.0008	0.0028	-0.0017	0.0048	-0.0133	-0.0001	-0.0045	0.0059
No. of leaves plant^{-1}	G	0.0439	0.0373	**0.0548**	0.0014	-0.0098	-0.0073	-0.0005	0.0044	-0.0120	-0.0137	-0.0091	0.0129	-0.0002	0.0048	-0.0115
	P	0.0413	0.0345	**0.0517**	0.0014	-0.0087	-0.0069	-0.0004	0.0042	-0.0112	-0.0129	-0.0085	0.0121	-0.0002	0.0045	-0.0107
Days to flower-ing	G	0.0026	-0.0004	-0.0006	**-0.0225**	-0.0004	0.0018	-0.0057	-0.0062	0.0005	0.0041	0.0052	0.0034	-0.0007	0.0010	-0.0044
	P	0.0022	-0.0003	-0.0005	**-0.0195**	-0.0003	0.0015	-0.0049	-0.0053	0.0005	0.0035	0.0044	0.0029	-0.0006	0.0008	-0.0038
No. of flower clusters plant^{-1}	G	-0.0128	-0.0035	-0.0087	0.0009	**0.0487**	0.0263	0.0004	-0.0149	-0.0047	0.0153	0.0073	-0.0069	-0.0084	-0.0032	-0.0073
	P	-0.0097	-0.0022	-0.0065	0.0006	**0.0387**	0.0199	0.0004	-0.0112	-0.0035	0.0116	0.0055	-0.0053	-0.0061	-0.0024	-0.0055
	G	-0.0340	-0.0397	-0.0201	-0.0118	0.0814	**0.1510**	-0.0053	-0.0933	0.0228	0.0490	0.0021	-0.0159	-0.0167	-0.0331	-0.0015
No. of flowers plant^{-1}	P	-0.0287	-0.0327	-0.0170	-0.0098	0.0658	**0.1279**	-0.0044	-0.0786	0.0192	0.0413	0.0017	-0.0134	-0.0141	-0.0280	-0.0013
	G	-0.0639	-0.0672	-0.0033	0.0966	0.0032	-0.0134	**0.3834**	0.3055	-0.1792	-0.1573	-0.0469	-0.0862	0.0617	0.0919	0.1196
No. of fruits plant^{-1}	P	-0.0695	-0.0736	-0.0034	0.1048	0.0039	-0.0145	**0.4191**	0.3346	-0.1951	-0.1701	-0.0513	-0.0936	0.0652	0.0992	0.1334
	G	0.0066	0.0206	0.0434	0.1472	-0.1641	-0.3306	0.4265	**0.5353**	-0.2475	-0.2681	-0.0605	-0.0686	0.1117	0.1713	0.1303
Fruit set per-centage	P	0.0057	0.0155	0.0395	0.1330	-0.1413	-0.3002	0.3898	**0.4882**	-0.2248	-0.2421	-0.0550	-0.0623	0.0993	0.1547	0.1220
	G	-0.1265	-0.1286	-0.2465	-0.0261	-0.1085	0.1703	-0.5281	-0.5223	**1.1298**	0.5732	0.5829	-0.3086	-0.2102	-0.3417	0.7644
Fruit weight (g)	P	-0.1242	-0.1202	-0.2417	-0.0258	-0.1016	0.1671	-0.5175	-0.5118	**1.1116**	0.5591	0.5707	-0.3029	-0.2043	-0.3353	0.7483
Radial diameter (mm)	G	0.0015	-0.0033	0.0121	0.0087	-0.0153	-0.0157	0.0199	0.0243	-0.0246	**-0.0485**	-0.0056	-0.0055	0.0058	0.0028	-0.0074
	P	0.0012	-0.0025	0.0098	0.0070	-0.0118	-0.0127	0.0160	0.0195	-0.0198	**-0.0394**	-0.0044	-0.0044	0.0048	0.0022	-0.0059
Polar diameter (mm)	G	0.0025	0.0026	0.0023	0.0031	-0.0021	-0.0002	0.0017	0.0015	-0.0071	-0.0016	**-0.0137**	0.0058	0.0032	0.0041	-0.0064
	P	0.0017	0.0017	0.0016	0.0022	-0.0013	-0.0001	0.0012	0.0011	-0.0048	-0.0011	**-0.0094**	0.0040	0.0022	0.0028	-0.0044
Leaf curl inci-dence percent-age	G	-0.0021	-0.0027	-0.0012	0.0008	0.0007	0.0006	0.0012	0.0007	0.0014	-0.0006	0.0022	**-0.0052**	0.0001	-0.0001	0.0026
	P	-0.0053	-0.0067	-0.0031	0.0020	0.0018	0.0014	0.0029	0.0017	0.0036	-0.0015	0.0055	**-0.0131**	0.0002	-0.0002	0.0066
	G	-0.0040	-0.0001	0.0002	-0.0018	0.0096	0.0062	-0.0090	-0.0116	0.0104	0.0067	0.0132	0.0006	**-0.0558**	-0.0488	0.0029
TSS°Brix	P	-0.0034	-0.0003	0.0002	-0.0014	0.0075	0.0053	-0.0074	-0.0097	0.0088	0.0058	0.0112	0.0006	**-0.0478**	-0.0414	0.0025
Ascorbic acid (mg/100g)	G	0.0126	0.0123	0.0059	-0.0029	-0.0044	-0.0149	0.0163	0.0218	-0.0206	-0.0039	-0.0206	0.0008	0.0596	**0.0682**	-0.0064
	P	0.0108	0.0102	0.0051	-0.0025	-0.0036	-0.0128	0.0139	0.0186	-0.0177	-0.0033	-0.0176	0.0007	0.0507	**0.0585**	-0.0056

Residual effect: Genotypic (G) = 0.1017 and Phenotypic (P) = 0.1054. (Bold diagonal values are direct effects).

Leaf curl incidence percentage: Based on the scale given by Joshi and Choudhary, 1981.

Total soluble solids (°Brix): Carried out on the selected samples were determined with a hand refractometer (Model: ATAGO, Tokyo, Japan). The refractometer was washed with distilled water each time after use and dried with blotting paper.

Ascorbic acid (mg/100 g): It was estimated using 2,6-dichlorophenol indophenol method as illustrated by AOAC (1975).

Statistical analysis: Data of all the previously mentioned characters were arranged and statistically analyzed, using the standard methods of the randomized complete blocks design as illustrated by Clewer and Scarisbrick (2001), using statistical software WINDOSTAT 9.1 developed by INDOSTAT services Ltd. Hyderabad, India.

Analysis of variance: Analysis of variance was done by the method suggested by Panse and Sukhatme (1985).

Estimation of correlations: The correlation coefficient analysis among all possible characters combination at phenotypic (rp) and genotypic (rp) level were estimated employing the formulae (Al-Jibourie *et al*., 1958).

$$\text{Phenotypic correlation} = V_{xy(p)} = \frac{COV_{xy(p)}}{\sqrt{[Vx(p) \times Vy(p)]}}$$

$$\text{Genotypic correlation} = V_{xy(g)} = \frac{COV_{xy(g)}}{\sqrt{[Vx(g) \times Vy(g)]}}$$

Where:

$COV_{xy\,(p)}$ = Phenotypic co-variance between variables x and y,

$COV_{xy\,(g)}$ = Genotypic co-variance between variables x and y,

$V_{x\,(p)}$ = Phenotypic variance for the variable x,

$V_{x\,(g)}$ = Genotypic variance for the variable x,

$V_{y(p)}$ = Phenotypic variance for the variable y,

$V_{y(g)}$ = Genotypic variance for the variable y.

Significance of correlation coefficient at both phenotypic and genotypic levels was tested by comparing table 'r' value with obtained value.

Path coefficient analysis: Path coefficient is a standardized partial regression coefficient and as such it is a measure of direct and indirect effect of a set variable (component characters) as a dependent variable such as fruit yield. The estimates of direct and indirect effect of component characters on fruit yield were computed using appropriate correlation coefficient of different component characters as suggested by Wright (1921) and elaborated by Dewey and Lu (1959). Thus, the correlation coefficient of any character with fruit yield was split into direct and indirect effects adopting the standard formula.

$$r_{iy} = r_{1i}P_1 + r_{2i}P_2 + r_{3i}P_3 + \ldots + r_{ni}P_n + \ldots + r_{ii}P_1$$

Where:

r_{iy} = Correlation of the *ith* character with fruit yield,

r_{ni} = Correlation between nth character with ith character,

n = Number of independent variables (component characters),

P_i = Direct effect of ith character on fruit yield.

Direct effects of different component character on fruit yield were obtained by solving the following equations.

$r_{iy} = [P_I]\,[r_{ij}]$ which can also be rearranged as $[P_I] = [r_{iy}]^{-1}\,[r_{ij}]$

Where:

$[P_I]$ = Matrix of direct effect,

$[r_{ij}]$ = Matrix of correlation coefficients among all the n components characters,

$[r_{iy}]$ = Matrix of correlation of all component characters with fruit yield,

r_{il} = Indirect effect of i^{th} character on fruit yield through first characters.

The residual effect was obtained by the following formula.

Residual effect = PR= $\sqrt{1}$ $-P_i r_{iy}$

Where: P_i and r_{iy} are as given above.

RESULTS AND DISCUSSION

Analysis of variance: The analysis of variance revealed significant differences among accessions for all the traits studies (Table 2). The highly significant differences among the accessions for all the traits indicate sufficient diversity among them which can be exploited through selection. Significant differences among the accessions for all the studied traits were also noticed by Barman *et al*. (1995); Singh and Raj (2004); Singh and Cheema (2005); Hidayatullah *et al*. (2008); Basavaraj *et al*. (2010); Dar and Sharma (2011); Kaushik *et al*. (2011); Porta *et al*. (2014); Santos *et al*. (2014b). In a breeding program, quantification of genetic variability of a population is a determining factor since it reveals the genetic structure of the populations (Santos *et al*., 2014a).

Correlation coefficient analysis: Yield of a crop is the result of interaction of a number of inter-related characters. Therefore, selection should be based on these component characters after assessing their correlation with yield. Character association revealed the mutual relationship between two characters, and it is important parameters for taking a decision regarding the nature of selection to be followed for improvement in the crop under study. The phenotypic and genotypic correlation among the yield and yield components in tomato are presented in Table 3 and Fig. 2. Significant correlation of characters suggested that there is much scope for direct and indirect selection for further improvement. Genotypic correlation coefficient provides measures of genetic association between traits and thus helps to identify the more important as well as less important traits to be considered in breeding programmes (Tiwari and Upadhyay, 2011). In general,

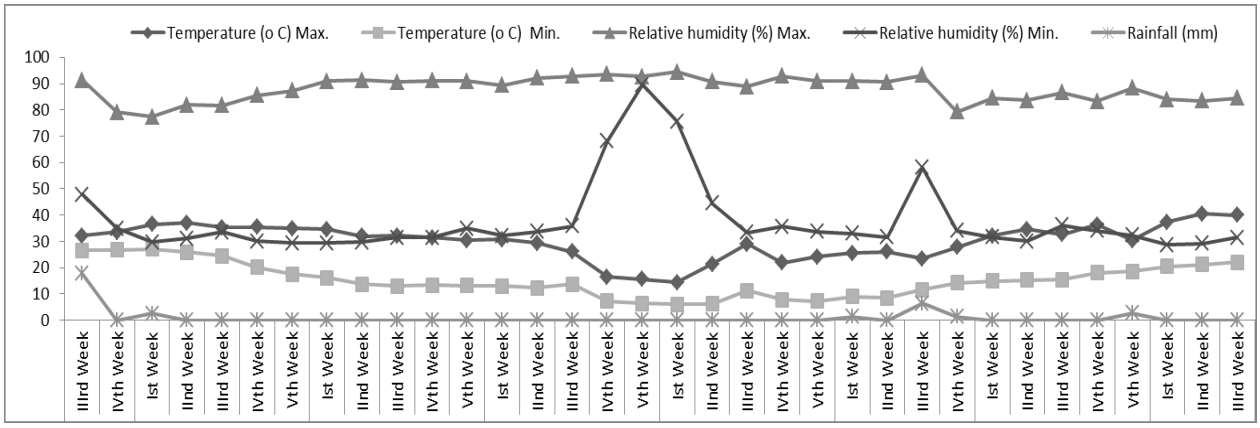

Fig. 1. *Mean weekly agro-meteorological observations recorded during crop season 2012-13.*

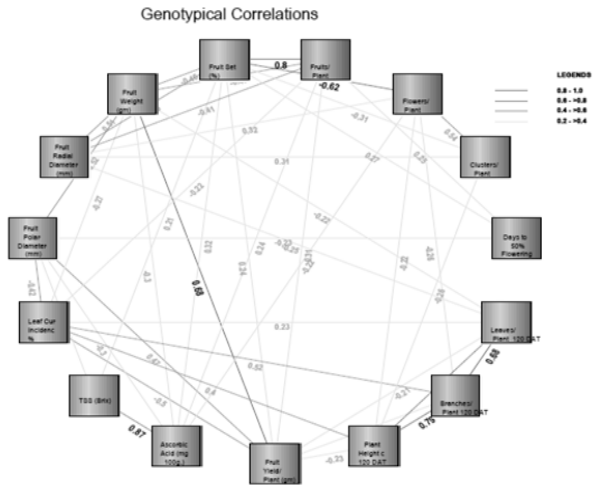

Fig. 2. *Genotypic correlation among various traits of tomato.*

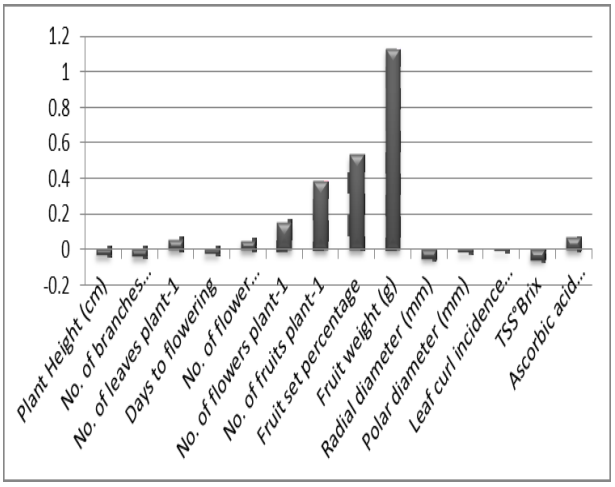

Fig. 3. *Direct (Path coefficient analysis) effect of quantitative and qualitative traits on fruit yield plant^{-1} at genotypic level.*

the coefficients of genetic correlation for all traits were higher than their corresponding coefficients of phenotypic correlation, thereby, suggesting strong inherent association among the characters studies. The low phenotypic value might be due to appreciable interaction of the accessions/genotypes with the environment. The higher genotypic correlation than phenotypic correlation have also been reported by Harer *et al*. (2002); Kumar *et al*. (2003); Golani *et al*. (2007); Dar *et al*. (2011); Tasisa *et al*. (2012); Srivastava *et al*. (2013); Santos *et al*. (2014a). The nature of genotypic correlation was similar to phenotypic correlation. However, in some cases correlation coefficients at genotypic level were significant, while at phenotypic level same were found to be non-significant (Kumari and Sharma, 2013).

In Solanaceaous crop plants, number of fruits and fruit weight are usually associated with higher yield. Our data also indicated significant positive genetic and phenotypic correlations between fruit yield plant^{-1} and number of fruits plant^{-1} (r = 0.3119 and 0.3184), fruit set percentage (r = 0.2434 and 0.2499), fruit weight (r = 0.6766 and 0.6731), polar diameter of fruit (r = 0.4687 and 0.4635), indicating that effective improvement in fruit yield plant^{-1} through these characters could be achieved. Similar results have also been reported by Kumar *et al*. (2003), Dhankhar and Dhankar (2006), Kumar *et al*. (2006), Tasisa *et al*. (2012), Reddy *et al*. (2013) for number of fruits plant^{-1}; Singh *et al*. (2004) for number of fruits plant^{-1}, fruit weight and fruit diameter; Ara *et al*. (2009), Kumar and Dudi (2011) for average fruit weight and number of fruits plant^{-1}; Rani *et al*. (2010), Sharma and Singh (2012) for fruit weight.

Plant height showed significant and positive association with number of branches plant^{-1}, number of leaves plant^{-1} and leaf curl incidence percentage at genotypic and phenotypic level. This is in agree-ment with the results found by Ogwulumba and Ugwuoke (2013) for number of leaves plant^{-1}; Meena and Bahadur (2015b) for number of branches plant^{-1} and number of leaves plant^{-1}. On the other hand days to flowering showed significant and positive association with number of fruits plant^{-1} and fruit set percentage at genotypic and phenotypic level. The results indicated that early flowering increase the number of fruits plant^{-1} and fruit set percentage.

The trait, number of fruits plant^{-1} showed significant and positive association with days to flowering, fruit set percentage, ascorbic acid and fruit yield plant^{-1} at

genotypic and phenotypic level, indicating that fruit yield may be obtained in an indirect manner with selection for increase in the number of fruits per plant. Similar types of findings were also reported by Das *et al*. (1998), Haydar *et al*. (2007), Hidayatullah *et al*. (2008), Islam *et al*. (2010), Dar *et al*. (2011) for fruit yield plant^{-1}, Meena and Bahadur (2015b) for fruit set percentage and fruit yield plant^{-1}. Its association with the character like fruit weight, radial diameter of fruit and leaf curl incidence was negative and significant which indicated that as the number of fruits increases, the individual fruit weight and radial diameter would decreases. Similar type of association was reported by Islam *et al*. (2010) for fruit weight and radial diameter of fruit; Srivastava *et al*. (2013) for fruit weight. In the present investigation, positive association of the fruit weight with radial diameter of fruit, polar diameter of fruit and fruit yield plant^{-1} was observed at both levels, which indicated that as the fruit weight increases the fruit yield plant^{-1} and those traits would also increase (Singh *et al*., 2004; Rani *et al*., 2010). Whereas, fruit weight was negative correlated with number of leaves plant^{-1}, number of fruits plant^{-1}, fruit set percentage, leaf curl incidence percentage and ascorbic acid indicated that as the fruit weight increases, those traits would decrease. These results are in confirmation with the findings of Srivastava *et al*. (2013) for number of fruits plant^{-1}.

Polar diameter of fruit showed positive significant correlation both at genotypic and phenotypic level with fruit weight and fruit yield plant^{-1} which indicated that as the polar diameter of fruits increases; the fruit weight and yield plant^{-1} would also increase. Prasad and Rai (1999), Agong *et al.* (2008), Islam *et al*. (2010) reported very high and significant correlation coefficient for fruit yield and fruit weight. TSS showed non-significant and negative correlation with number of leaves plant^{-1}, number of flower clusters plant^{-1}, number of flowers plant^{-1}, fruit weight, radial diameter of fruits, leaf curl incidence percentage and fruit yield. It has also been reported that a non-significant association of TSS with yield plant^{-1} and fruit weight (Nirmaladevi and Tikoo, 1992; Premalakshmi, 2001). In the present investigation the absence of significant association was not only with yield but also with fruit weight and other traits were seen. This would help the breeder to develop good F_1 hybrids with better yield as well as TSS. The TSS had strong positive and significant inter association with ascorbic acid, which was also earlier reported (Aruna, 1992; Jawaharlal, 1994; Indu Nair, 1995). Ascorbic acid (mg/100 g) showed significant and positive association with number of fruits plant^{-1}, fruit set percentage and TSS at genotypic and phenotypic level. The result was in full agreement with earlier studies by Meena and Bahadur (2015b) for TSS.

Path coefficient analysis: Yield is the sum total of the several component characters which directly or indirectly contributed to it. Correlation studies give an idea about the positive and negative associations of different characters with yield and also among themselves. However, the nature and extent of contribution of these characters towards yield is not obtained. Hence, path coefficient analysis was used to make partition of the correlation coefficient of the different characters studied to know direct and indirect effects on yield. The information obtained helps in giving proper weightage to the various characters during selection or other breeding programme so that the improvement of desirable traits can be achieved effectively (Bhatt, 1973; Meena and Bahadur, 2015b).

The results of the present investigation on path coefficient analysis as presented in Table 4 revealed that fruit weight had a very high positive direct genotypic and phenotypic effect 1.1298 and 1.1116, respectively on fruit yield plant^{-1} (Fig. 3) followed by fruit set percentage (0.5353 and 0.4882), number of fruits plant^{-1} (0.3834 and 0.4191), number of flowers plant^{-1} (0.1510 and 0.1279), ascorbic acid (0.0682 and 0.0585), number of leaves plant^{-1} (0.0548 and 0.0517) and number of clusters plant^{-1} (0.0487 and 0.0387). The results in accordance with the finding of Dudi and Kalloo (1982), Verma and Sarnaik (2000), Ara *et al*. (2009), Kumar and Dudi (2011), Sharma and Singh (2012) for fruit weight and number of fruits plant^{-1}; Golani *et al*. (2007) for fruit weight; Manna and Paul (2012) for number of fruits plant^{-1}, fruit weight and ascorbic acid; Reddy *et al*. (2013) for number of fruits plant^{-1} and ascorbic acid. On the other hand the traits, viz., plant height, number of branches plant^{-1}, days to flowering, radial diameter of fruit, polar diameter of fruit, leaf curl incidence percentage and TSS had negative direct effect toward yield at the genotypic as well as phenotypic level. Similar results have also been reported by Singh *et al*. (2004) for plant height and TSS; Asati *et al*. (2008) for number of primary branches plant^{-1} and days to flowering; Dar *et al*. (2011) for TSS; Tiwari and Upadhyay (2011) for plant height; Reddy *et al*. (2013) for days to flowering and number of primary branches plant^{-1}.

Plant height exhibited positive indirect effect on fruit yield via days to flowering, number of flower clusters plant^{-1}, number of flowers plant^{-1}, number of fruits plant^{-1}, fruit weight, radial diameter of fruit and polar diameter of fruits. Similar results have also been reported by Tiwari and Upadhyay (2011) for days to flowering and fruit weight. Days to flowering exhibited positive indirect effect on fruit yield via plant height, number of flowers plant^{-1}, fruit weight, radial diameter of fruit, polar diameter of fruit, leaf curl incidence percentage and ascorbic acid. Similar results have also been reported by Tiwari and Upadhyay (2011) for fruit weight. TSS °Brix exhibited positive indirect effect on fruit yield via number of leaves plant^{-1}, number of flower clusters plant^{-1}, number of flowers plant^{-1}, fruit weight, radial diameter of fruit,

polar diameter of fruit and leaf curl incidence percentage.

Conclusion

In present investigation, fruit weight showed high positive and direct effect had significant positive correlation with fruit yield plant^{-1}. Therefore, the fruits with higher weight should be considered in selection criteria for increasing fruit yield plant^{-1}. The present study suggested that more emphasis should be given to selecting accessions with high fruit weight. Directly or indirectly all characters showed positive effect on fruit yield plant^{-1}. The residual effect of the genotypic and phenotypic path analysis was very less *i.e.* 0.1017 and 0.1054, respectively. This indicates that the characters chosen for the present study is the main components of yield and that the variability in yield is accounted by the characters chosen for this investigation to a considerable extent. Correlation and path coefficient studies suggested that the selection should be primarily based on the component characters which exhibited significant positive correlation with yield and also had either direct or indirect effect on yield. This may lead to development of high yielding accessions in tomato.

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